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Quality of Experience (QoE) and Quality of Service (QoS) in UAV Systems

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Quality of Experience (QoE) and Quality of Service (QoS) in UAV Systems

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1.1 UAV – A - Cyber Physical System

"Cyber-Physical Systems (CPS) are integrations of computation and physical processes [11]. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. For operation, they require data. An Unnamed Aerial Vehicle (UAV) is an autonomous system which operates automatically without a human pilot; flight operates various degree of autonomy is controlled via computers [1] and can acquire unique data about physical process, thus allowing for real-time monitoring, management, control and actuation tasks in a CPS to be achieved. A UAV system also is known as a drone plane, which is commonly used for monitoring prohibited actives and target militants without risking the life of security forces. UAV was initially designed and developed for the military purpose and mostly used in remote sensing. Nowadays, UAV are used in much broader applications such as in agricultural, recreational, scientific, commercial as well as in applications such as policing, peacekeeping and surveillance, product deliveries, aerial photography, smuggling and drone racing [2, 3]. UAV collects data such as image capturing, video recording, measure temperature, humidity, crop identification, forest and water management in remote areas, mountains and agriculture fields [4]. UAV provide better monitoring and image data capturing with high resolution compared to satellite remote sensing.

There are many types of UAVs such as vertical takeoff and landing (VTOL) and fixed-wing UAVs developed for AggieAir, which are used for various application and research purpose. Figure 1.1 and 1.2 capture the AggieAir hexorotor VTOL and ying AggieAir Mnion separately [5]. Fixed-wing UAVs are used in Fish tracking as shown in Figure 1.3 [6]. Figures 1.4, 1.5 & 1.6 show the application of UAVs in detection for Bear River Migratory Bird Refuge (MBR) [7], Precision agriculture [8] and Wetland detection [9].

Fig. 1.1 AggieAir-VTOL (hexorotor).

Fig. 1.2 AggieAir-Minion.

Fig. 1.3 AggieAir for fish tracking.

Fig. 1.4 AggieAir for bird refuge.

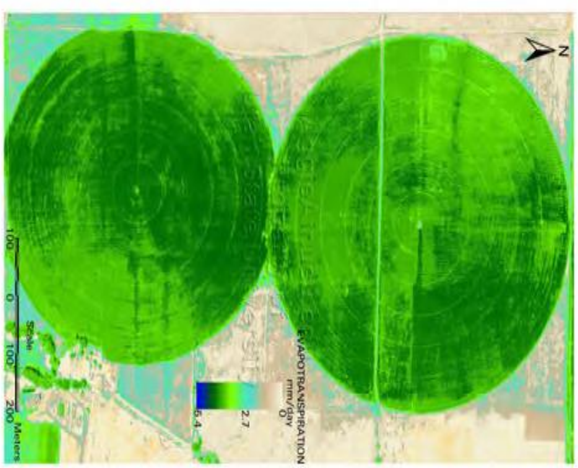

Fig. 1.5 AggieAir for agriculture.

Fig. 1.6. AggieAir for wetland.

Fixed-wings UAVs are used for long duration task and high altitude [10]. Whereas, VTOL UAVs have specific points of interest, for example, floating ability and no space confinement for departure and landing, which are helpful for applications, for example search and surveillance, the static image capturing, and crop identification. Contrasted with fixed-wing UAVs, VTOL UAVs are more reasonable to be utilized as a part of the smaller range with more exact location. The utilization of VTOL UAVs is shown in Figures 1.7 to 1.10.

Fig. 1.7 High quality photo capturing.

Fig. 1.8 Algae growth.

Fig. 1.9 Powerline inspection.

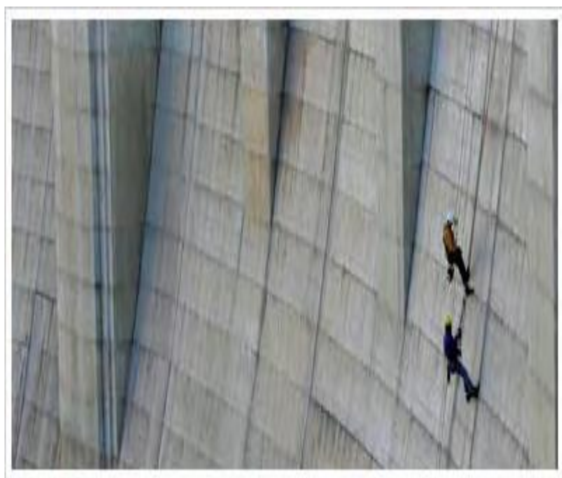

Fig. 1.10 Dam inspection.

The economic and societal potential of Cyber Physical UAV Systems (CP-UAVS) is vastly greater than what has been realized in many fields, and major investments are being made worldwide to develop the technology. There are considerable challenges, particularly because the physical components of such systems introduce safety and reliability requirements qualitatively different from those in general-purpose computing. Moreover, physical components are qualitatively different from object-oriented software components. Standard abstractions based on method calls and threads do not work." The architecture of the CP-UAVS is given in the Figure 1.11.

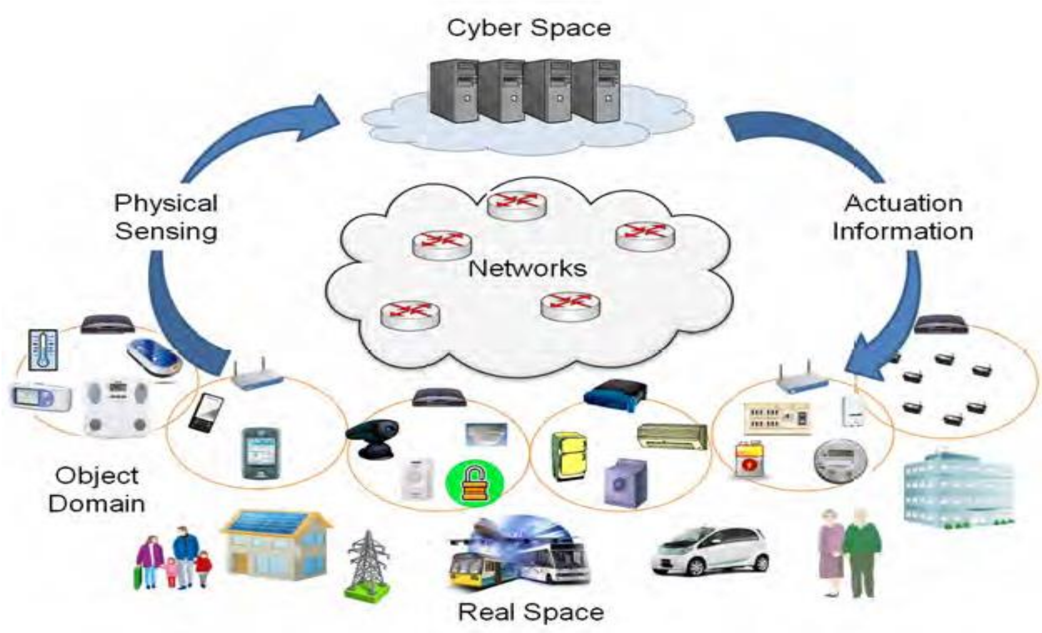

Figure 1.11 An example for CPUAVS architecture. [12]

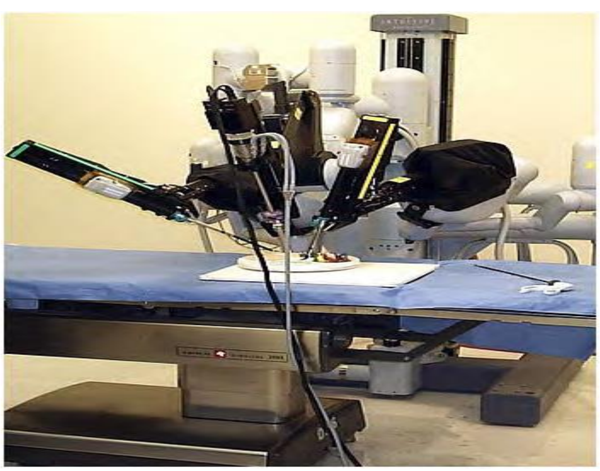

Fig. 1.12: Robotic surgery [13].

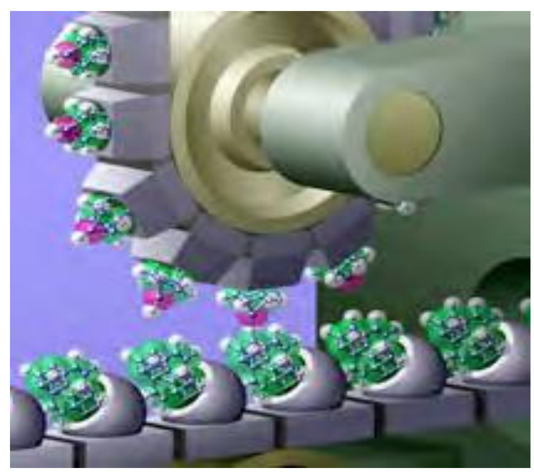

Fig. 1.13: Nano manufacturing [14]

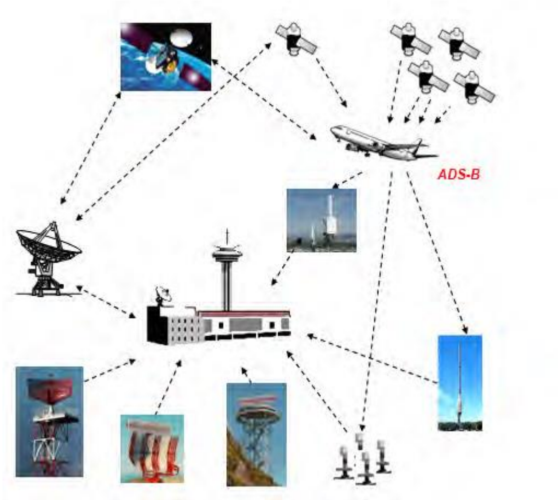

Fig. 1.14: Air traffic control.

Fig. 1.15: Health monitoring system.

1.1.1 Introduction to QoE & QoS in CPUAVS

The Quality of Service (QoS) is used measure the performance of a CPUAV system. The transmission network, image capture and video recording are the parameters where UAV system has to provide QoS. QoS is based on the objective parameters to improve and measure the performance of a system whereas, the Quality of Experience (QoE) is based on the level of the user’s satisfaction, enjoyment and expectations – a subjective measure. QoS is a major concern in UAV systems because these systems are used for real-time monitoring and targeting for a different purpose and during the monitoring, these systems capture high definition (HD) quality images, record video and send via a network to the central station. If middle network between the UAV system and central station did not provide QoS then real time data will not be accurate and information losses occur which make problems in operation resulting in inaccurate results. Information received at the central station with data loss or delay (packet loss, reorder and delay) decrease the satisfaction level of the user (operator) to perform operations using UAV systems. Network QoS degradation affects the real time monitoring via video recording and data loss reduces the image quality which contains important information, decreasing the QoE of the user.

1.1.2 Definition of Quality of Experience (QoE)

Quality of Experience (QoE) is used to measure customer needs and try to provide services according to their needs. QoE is users’ evolution of data about network and services provided by the network [17]. The definition of QoE according to [18] is *“the degree of delight or annoyance of the user of an application or service*”. In a more general perspective *“QoE is defined as a measurement of customer satisfaction or customer performance dependent on objective or* *subjective measure of using any service or product"* [19]. There are different definitions of QoE provided by academia and industry. The International Telecommunication Union ITU-T defines QoE [20] as *"The overall acceptability of an application or service, as perceived subjectively by the end-user"*. Laghari and Connelly define [21] QoE as *"QoE is a blueprint of all human subjective and objective quality needs and experiences arising from the interaction of a person with technology and with business entities in a particular context"*. Vendors of product use QoE to get information about user needs and demand, which are changed over time [22]. They use interviews, web based surveys and questionnaires to get subjective information from users about a product or service [23].

Nowadays Quality of Experience (QoE) is used to improve the services and analyse the user requirement or needs from the system and make system more user-driven. Previously QoS was used to improve the services of the system and technical parameters were changed such as network device (router, interface cards and bandwidth), camera lenses to capture HD and image and record video but user requirements were not considered during the update of the system.

1.1. 3 Definitions of QoS

QoS helps manage packet loss, delay and jitter on the network infrastructure. Cisco defines *"Quality of Service (QoS) as the capability of a network to provide better service to selected network traffic over various technologies, including Frame Relay, Asynchronous Transfer Mode (ATM), Ethernet and 802.1 networks, SONET, and IP-routed networks that may use any or all of these underlying technologies"*[24] . International Telecommunication Union (ITU) defined QoS as *"Totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service"* [25]. Service provider used differentiated services (DiffServ) and integrated services (Inserv) to provide QoS to the user and assess and ensure quality but this does not ensure the service level agreement (SLA) between the service providers (SPs) and customers [26]. Diffserv and IntServ are two methods can provide the flexibility to access the quality of bandwidth and delay efficiently.

QoS is a major concern in the communication of UAV systems with central datacentre because these systems are used in real time environment to monitor flood, war activities, fire in the forest and vehicle tracking in a remote location to name a few. Such environmental conditions affect the wireless transmission.

1.2 Relationship between perceived multimedia QoS/QoE, access network impairments and video content type in UAV systems

QoE of multimedia streaming is based on the network impairment and video content type being recorded by the CPUAV systems. Figure 1.16 shows the end-to-end multimedia QoE concept over wireless access networks [59]. At the sender side multimedia is encoded and packetized, whereas, at the receiver side, it is depacketized and decoded.

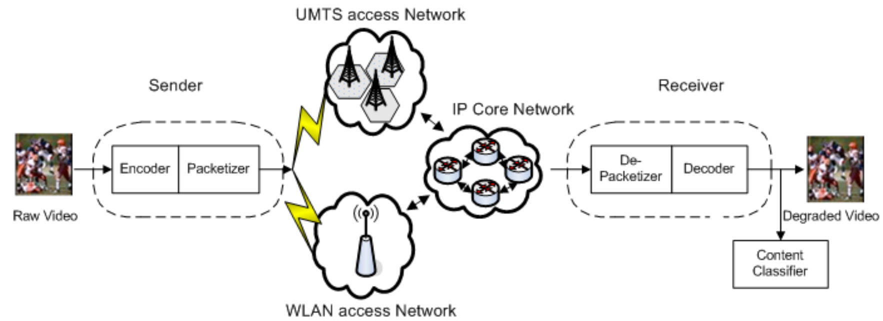

Figure 1.16 An overview of end-to-end multimedia QoE

QoS is measured objectively from network impairments such as packet loos, delay and reordering whereas, QoE is subjective and is measured from the QoS as well as users perception of the received multimedia.

The QoS of a CPUAV system is measured as the overall the performance of the network both from the access and the core IP network. Whereas, QoE is based on the measured QoS of the CPUAV system, for example in real-time video monitoring and transmission of the application scenario as perceived by the user. QoSof transmitted video contents is based on the different factors such as video format (size), objects or information which contains the video sequence, frame rate, and bitrate.

1.2.1 Parameters that impact QoS/QoE

The parameters that impact the QoS of CPUAV system performance can be summarized in Figure 1.17.

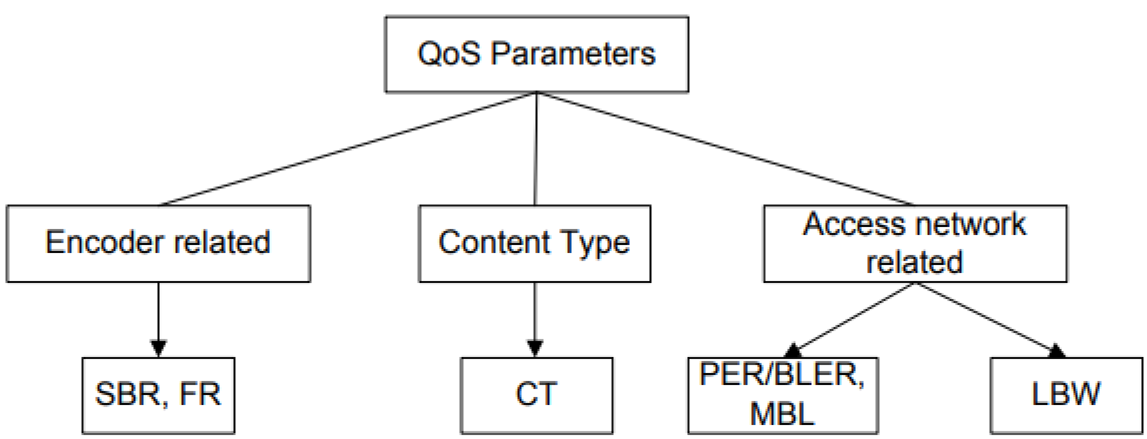

Figure. 1.17 QoS Parameters in a CPUAV system

In the Figure 1.17 QoS parameters are broadly divided into application level, access network level and the content type parameters. The access network level parameters include packet loss, router waiting and queue delay, packet reordering due to multipath routing, link bandwidth (LBW), mean burst length (MBL), etc. The application level parameters comprise of video codec, bitrate, frame rate and data rate for presenting quality information to users. In addition, the video content type also impacts the QoS. For CPUAV systems it depends on the two aspects -first the Camera device used for image capturing and video recording and second the access network for transmission Mostly high definition (HD) camera with the good quality lens are fixed in UAV systems to capture multimedia. Transmission of HD multimedia contents require high bandwidth network and low traffic but network resources are not available so this can cause delay and loss of multimedia data (packets lost).

1.2.2 Impact of Cloud distance on QoS/QoE

Cloud distance is also important for QoS/QoE of CPUAV system because the long distance of the cloud data center from the UAV system add extra network delay in data transmission. In short distance cloud and UAV, communication have less delay because number of routers and connecting interfaces are low compared to the long distance cloud and UAV where large number of routers and interfaces of different service providers add extra delay. Organizations prefer high quality video and images by UAV systems, but due limited network bandwidth and long distance of cloud for UAV systems; they can-not receive high quality video smoothly which degrades the QoE of UAV users [27]. Accessing direct UAV system like server client system is different but if UAV system is controlled via cloud then impact is different because request goes to cloud management software then it will be distributed in internal racks and clusters which also add cloud internal network delay in data receiving and command forwarding to UAV systems. Increasing network distance between the UAV system and cloud service provider have an impact on startup delays and waiting time until the service setup of QoE.

1.3 QoS/QoE Monitoring framework in CPUAV systems

QoS/QoE monitoring framework of UAV systems is based on the objective QoE. *"Objective QoE can be measured by using two methods (i) objective technical factors which infer QoE from available QoS data, and (ii) objective human factors which are related to the human physiological and cognitive system"* [26]. In QoS/QoE monitoring framework of UAV systems, we used objective QoE, which is based on the technical QoS data to evaluate the performance of QoS system and better management of operations.

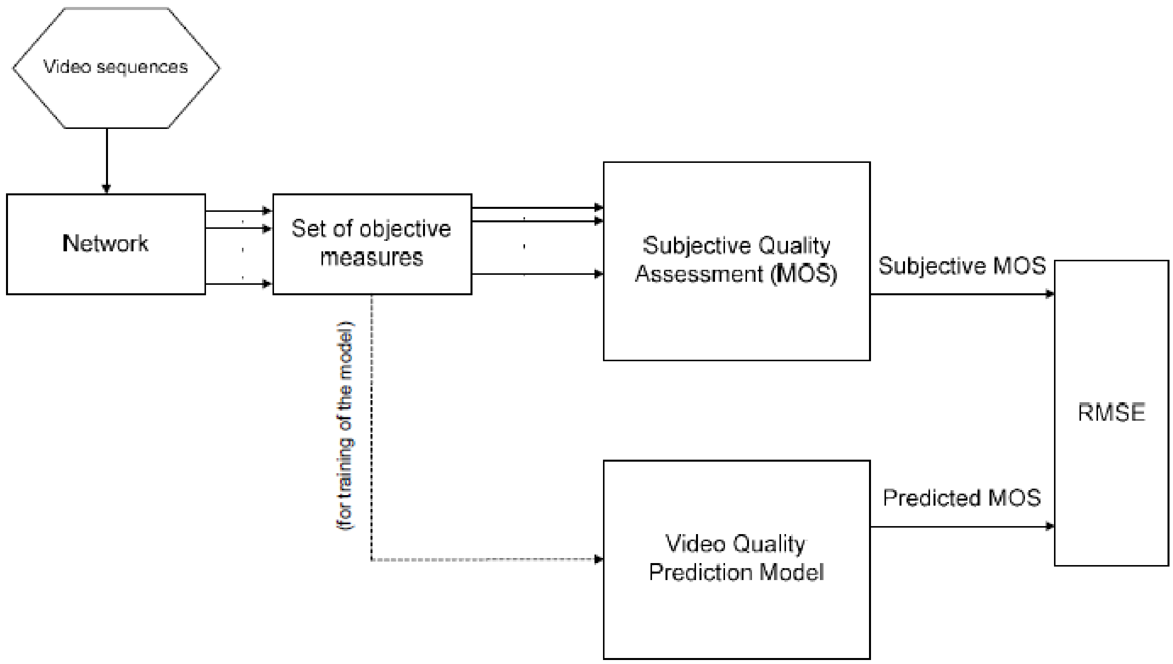

Figure 1.18 (a) Block diagram of the video quality prediction model

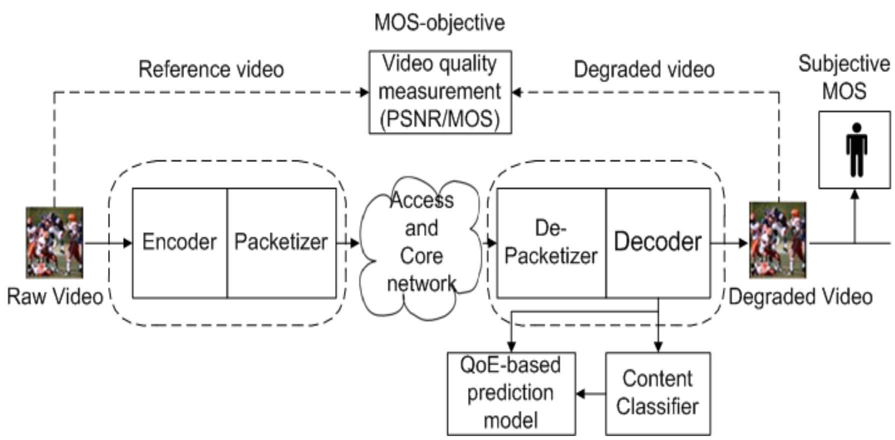

Figure 1.18 (b) End-to-end multimedia QoE/QoS framework

Figure 1.18 (a) and (b) shows the end-to-end framework of measuring QoS and QoE of multimedia from a CPUAV system non-intrusively. The video recorded is encoded, digitized and send over access and core IP network. At the receiver side, the video is depacketized, decoded and reconstructed. The QoS is measured either bu objective parameters such as VQM, PSNR, etc, or subjectively measured by calculating the Mean Opinion Score (MOS) based on human perception of the received video. This data helps in developing non-intrusive video/multimedia models that can measure QoE. The MOS ratings are given in Table 1.

Table 1. Mean Opinion Score

MOS	Quality	Perception
5	Excellent	Imperceptible
4	Good	Perceptible
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

Objective QoE monitoring is based on the agent technology and QoS data can be retrieved by applied functionalities, which are provided by simple network management protocol (SNMP) [28]. SNMP is a popular protocol for network management. It is used for collecting information from, and configuring, network devices, such as servers, printers, hubs, switches, and routers on an Internet Protocol (IP) network. Microsoft Windows Server 2003 provides SNMP agent software that works with third-party SNMP management software to monitor the status of managed devices and applications. SNMP use agents to retrieve QoS data of network such as route information from cloud to UAV system, number of packets in and out and number of network interfaces. SIGAR (https://support.hyperic.com/display/SIGAR/Home) is used for low level system information such as total memory, used memory, actual free memory, CPU utilization and specific information e.g memory and CPU consumed by a process [29]. In our proposed framework shown in Figure 1.19, we monitor Application level QoS (AQoS)/ and Network level QoS (NQoS) parameters to estimate QoE from them. In QoS/QoE framework of CPUAV system, management software monitors cloud environment for free resources like computation, storage and load on the internal cloud network. Monitoring of QoS data from cloud to CPUAV system contains distance from cloud to user, number of routers between them, specific delay on network traffic passing from router, network bandwidth, type of network, UAV system capability, system usage, memory usage (CPU and memory usage has huge impact on performance of accessing cloud), particular delay on router queue, this information for administration to understand the deficiencies in QoS operating UAV systems.

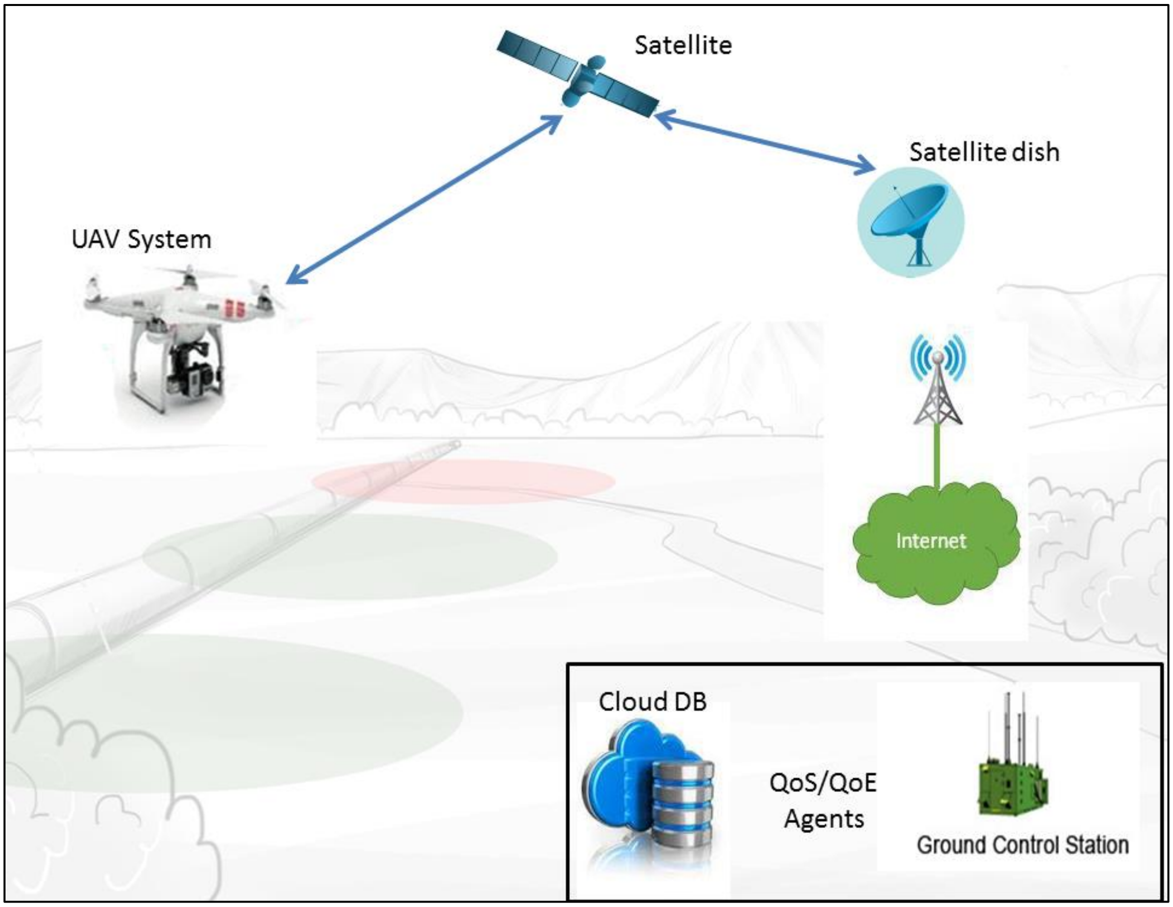

Figure 1.19. QoS/QoE Monitoring framework in UAV systems

1.3.1 Application level management

QoS/QoE monitoring at application level helps to analyse the performance of applications and manage them properly. UAV system QoS/QoE monitoring framework also contains the application level management functionality which automatically monitors the network traffic of applications which based on the protocols such as applications FTP (File Transfer Protocol), HTTP (Hyper Text Transmission Protocol), RDP (Remote Desktop Protocol), RTP (Real Time Protocol), CIFS (Common Internet File System) or SQL , and Exchange. This section also monitors the hardware resources utilization as well as free resources and type of task CPUAV system currently perform such as image capturing or video recording and streaming.

1.3.2 Network level Management

Network level management of QoS/QoE framework for UAV system is based on the monitored QoS data of network which is used for sending and receiving data from cloud datacentre to CPUAV system. Agents run from control centre to UAV system and cloud storage, which collect data of link capacity between the UAV system and cloud; measure data send and received at UAV system interface as well as on cloud interface, overall network traffic data. The collected data is stored and used for analysis of network to find the error rate, packet loss, delay and reordering which will help for proper management of the network.

1.3.3 Cloud Distance Management

Real time video monitoring and captured images are stored in cloud database connected to the ground station from CPUAV systems. Cloud distance has an impact on the QoS/QoE of UAV system because the long distance of cloud adds an extra delay in sending and receiving data. Internal cloud communication between the racks and clusters for data storage and retrieval for analysis also make delay due to the congested traffic of the internal network. Avoiding these issues we prefer nearby location cloud for data storage in QoS/QoE framework of UAV systems. Cloud data centre near to ground station where UAV system is controlled or using own cloud for data storage and information retrieval will improve the service of the CPUAV system.

1.3.4 QoS/QoE service level management

QoS/QoE service level management of CPUAV system is the monitoring and management of the QoS of an entity's key performance indicators (KPIs). Traditionally service level management is accomplished using traditional monitoring tools like Microsoft SMS but service management level is a problem in UAV system networks because networks are of compositional nature, dynamic and flexible and services accessed in remote areas. QoS/QoE monitoring framework of UAV system uses agent technology to measure network resources such as network bandwidth, utilization of network at peak level at different hours and error rate. Service level management will compare actual performance with pre-defined expectations, determining appropriate actions, and producing meaningful reports [30].

1.5 QoS/QoE metrics in UAV systems

The following QoS/QoE metrics have been defined for UAV system communication automatically measure by QoS/QoE framework and report by the operator on the activation of UAV system.

- **Throughput:** The amount of data per flow in a network is known as its throughput. Throughput is a measure of how many bits of data are transferred in a network system in a given amount of time. It is utilized in a broad range such as CPU of computer process amount of data transferred via memory and performance of the operating system and network systems such as ad hoc or mobile networks, whose capacity grows with network size or decreases which introduce the limitation of radio spectrum.
- **Network (Packet loss and Delay):** Packet loss and packet delay are the network traffic parameters which affects the transfer of data from cloud to UAV system. In packet loss situation information packet is destroyed and never recoverable. If packets that contain input action information are lost than the operator will lose control of the UAV system,

affecting the performance. Also, information packets that arrive after a delay to the UAV system results in input packets sent late to cloud causes unconventional monitoring.

- **Resources:** this metrics contains log and report of hardware resources of UAV system such as overall system capability, memory usage, and CPU utilization for each task, free resources and management of resources. Monitoring of resources will help to manage the performance of CPUAV systems.

1.5.1 Mapping of QoS to QoE

The mapping of QoS to QoE function is based on the monitoring system, AQoS and NQoS, and cloud distance. In the QoS/QoE monitoring framework of UAV system, QoE is based on the agent's captured technical QoS data which contains information of video, image, network and cloud distance where data will be stored and retrieved for analysis. If results of collected data contain long network delay or packet less for video streaming, the insufficient memory of UAV system or low processing power which takes time to process to instructions from operator cause low QoS/QoE. These phenomena decrease the QoE of CPUAV systems, dissatisfied performance for video recording/image capturing and streaming to control centre. The QoS parameters can be mapped either objectively to the QoE or subjectively.

1.5.2 Subjective vs Objective Measurement

Subjective QoE measurement is based on interviews, questionnaires, web surveys and complaint boxes [31]. Subjective testing, however, is expensive and time-consuming and less accurate as compared to objective QoE [32]. Subjective measurement, on the other hand, refers to measures that have to do with what people say and actually experience. Sometimes the subject is visual blind or unconscious, this situation causes inability to judge the exact experience of service and can provide wrong information. Greedy nature of users to get more favor from service provider mentioned in service level (SLA) also provides negative feedback which is also a problem in subjective QoE assessment [33]. Therefore, subjective QoE measurement accounts for human perception.

Objective QoE measurement is based on the technical QoS data and MRI physiological tests of people that how subjects perform a task, irrespective of what they experience while performing tasks [34]. Objective assessment of QoE provides more accurate data as compared to subjective because in objective method data is captured via agent based software, log reports without the involvement of subjects to provide their feedback [35].

There is still no consensus about whether to use objective or subjective performance to determine whether something is consciously perceived or not. The problem with subjective performance (just asking "did you see something, yes or no") has been that it is prone to criterion changes. For example, someone might be much more prone to answering that they did not see anything when 90% of the trials are non-targets compared to only 10% of the trials. This is something that can partially be solved using signal detection theory, by determining not only the number of hits but also the number of false alarms. But much of it hinges also on the way the question is framed, and how the respondent is encouraged to answer ("yes/no" type question seem to naturally tap more into subjective experience, whereas two-alternative forced choice questions tap more into objective performance, although both types of questions can be framed in such a way that they tap into either, depending on what the instructions look like).

1.5.3 Tools to Measure QoS/QoE

To assess the QoS/QoE there are many crowd-sourcing frameworks used to collect online QoS/QoE, tools given by industry and reference models provided by the researchers. Simple manual methods are used for subjective QoE such as interviews, questionnaire and complaint boxes to measure QoE of users and collected data analysed by using MS Excel and Gephi tools [53, 60]. Advanced automatic crowd-sourcing tools are also developed to capture QoS/QoE in the runtime environment and data analysis. Crowd-sourcing is an emerging technique that can be employed to measure the QoE at the end user but in an uncontrolled environment. Crowd-sourcing frameworks provided to collect QoS/QoE of image and video by Sajjad et al. [36] that measures the QoE of online video streaming, as perceived by end-users. The tool also measures important QoS network parameters in real-time (packet loss, delay, jitter and throughput), retrieve system information (memory, processing power etc.), and other properties of the end-user's system. Related crowd-sourcing frameworks also provided by [37 - 41] for image and video QoS/QoE assessment.

Objective QoE tools are given by Niche vendors to measure the QoS/QoE of multimedia streaming by capturing technical QoS data [42, 43]. Casas et al. [44] provided objective QoS/QoE measuring model based on the machine learning, which is capable to predict the QoE experienced by the end user of popular smartphone apps (e.g., YouTube and Facebook), using as input the passive in-device measurements. Objective QoS/QoE tools are also included in crowd-sourcing frameworks to capture automatically QoS technical data [26, 32, and 38].

The reference models are used by researchers to measure the QoS/QoE in real time environments such as no-reference model [45, 46], reduced-reference model [47] and full-reference model [48].

1. The no-reference model has no knowledge of the original stream or source file and tries to predict QoE by monitoring several QoS parameters in real-time. Figure 1.20 shows the concept behind no-reference video quality measurement.

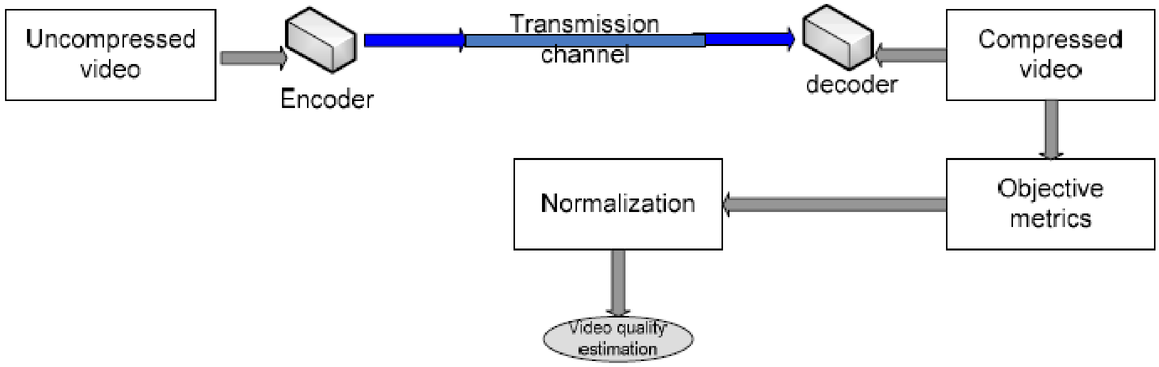

Figure 1.20 Non-intrusive (no-reference) video quality measurement

2. The reduced-reference model has some limited knowledge of the original stream and tries to combine this with real-time measurements to reach a prediction on the QoE.
3. The full-reference model assumes full access to the reference video, possibly combined with the measurements conducted in a real-time environment.

1.6 QoS/QoE of real-time multimedia content delivery in CPUAV Systems

The CPUAV systems record video in remote areas such as mountains, forest and desert etc. using high altitude moving the camera to cover wide area [49]. Monitoring video is captured with cameras mounted on the UAV system and video signal encoded and transmitted with low latency to the ground station to monitor the particular task and respond quickly to avoid hurdles. Several researchers have provided application scenario of real-time multimedia content delivery during the monitoring of war, forest, traffic surveillance and oil fields etc. [50, 51]. The application usage of UAV system and multimedia contents delivery of real-time monitoring are given 1.6.1 and 1.6.2 sections respectively.

1.6.1 Application scenario 1: UAV systems in detecting street crimes

The UAV system proposed to monitor and automatically target in congested street based on the real-time image processing by Shahid et al. [52]. The design of proposed drone plane is smaller for moving easily in congested streets during monitoring and targeting. The drone plane is based on HD resolution camera for the visionary system. The proposed drone plane shown in Figure 1.21contain cameras for capturing images and recording videos, weapons for targeting, control unit based on two processing unit for controlling all operations.

Fig. 1.21 Scenario of crime scene image capturing via proposed drone

Drone plane is based on two different processing units, these units are interconnected to each other for instruction sharing and controlling all operations during monitoring such as moving between the buildings, recording crime scene and targeting. The 1st processing unit will handle the operation of image processing because image shape and shadow detection require high computational power in real time image processing. The crime scene contains different objects like victims and criminals with armed guns. It’s cumbersome in the field of artificial intelligence and image processing to find accurate information in the image and make perfect decision on the behalf of extracted information. Many techniques are available for image capturing and video recording, one of them is satellite imaging which is available online, ground information can be acquired by LANDSAT imagery but the resolution is very low. If data is collected from Quickbird or MODIS of high resolution then it will be costly. Low resolution data can be processed by image processing techniques but without guarantee for ideal accuracy. Ultra-light UAVs can also be used for this purpose of imagery and the accuracy depends on the resolution of real images. Sometimes the results are not more accurate from ultra-light but can be improved by computer vision techniques. The 2nd processing unit will control physical movements of drone and it is about saving itself from the target of robbers and light cables. The second processing unit also controls all the mechanical operations and targeting guns during the flying time of drone. The processing units with specific information and interconnection between them are given in Figure 1.22.

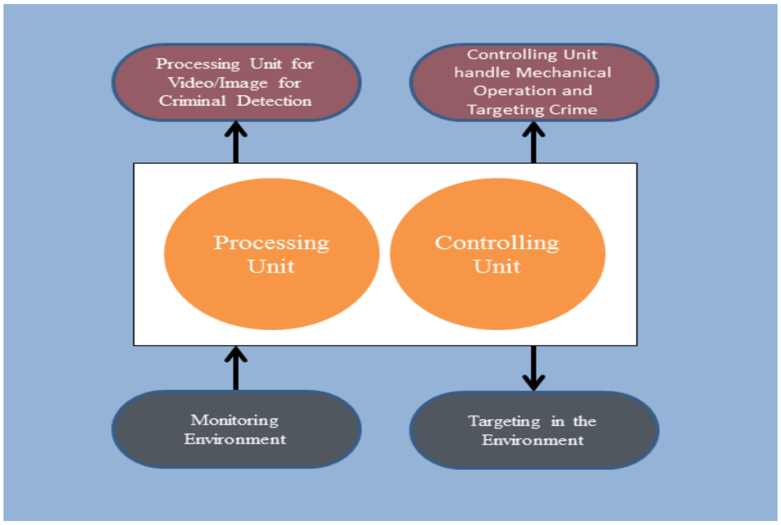

Fig. 1.22. Architecture of proposed drone Model

The drone design is proposed for four hours monitoring in particular area from its central maintenance location. There is a limitation of flight time in UAVs which depends on their model so the minimum flight time starts from 30 minutes to maximum time is 10 hours and it can be extended up to 24 hours. The range and monitoring area will be divided between the drones and every drone plane can monitor the 5km circular area. Proposed drone plane can be controlled from a central location via the operator and also has the functionality to automatically perform all operations without intervention or control of the operator. The priority of control is given to the operator to quit monitoring operation before the critical condition of the battery. If drone plane only set for monitoring not for targeting robbers, then robbers run away from the range of current drone to the range of another drone plane. Then it will transfer the control of monitoring process, location and movement direction of robbers to next cell drone plane via handshaking method of mobile communication. The circular area monitoring concept is same as telecom cells. Every drone plane of a particular area will be connected to central location office via a satellite network.

1.6.2 Application scenario 2: CPUAV systems in traffic congestion management

CPUAV systems are also designed for traffic congestion management via real-time monitoring of traffic [54, 55]. Federal Aviation Administration (FAA) and The National Aeronautics and Space Administration (NASA) collaborate to develop Unmanned Aircraft System Traffic Management (UTM). The purpose of developing UTM is to control air traffic congestion and avoid collision of UAV system with other air vehicles. Cloud-based UTM system will help and ease to the operator to manage air traffic to avoid collisions of UAV's being operated beyond the visual line of sight at low altitude [56]. To test UTM technologies, NASA works with many partners that provide vehicles and other subsystems, with NASA responsible for airworthiness, range and flight safety. To conduct UTM tests with its public, academic and private partners, NASA uses its Memorandum of Agreement (MOA) with the FAA for UAS testing and operations in certain types of remote airspace [57].

UTM provides information of wind and congestion to operators which help to manage UAV and the collected database will help them avoid collision with stationary objects and buildings. The system provides information of all objects and buildings in the environment and suggests user to the safe location where the user can safely fly. It provides alert if any critical situation will occur due to weather or not fly in restricted areas such as airport and heavy air traffic or other operations, this will help the user to choose a different path. Fig. 1.24 demonstrates this application.

The UTM will come in four builds used in four different risk-based situations. The first build is used in unpopulated areas, where safely fly and landing. The second build is used for safely fly or operations in low populated areas. The third build will be used for limited contact with manned aircraft, such as for package deliveries, while the fourth build is reserved for more missions in urban environments. Each build enables certain types of missions and provides certain services, and supports the missions and services of the previous build.

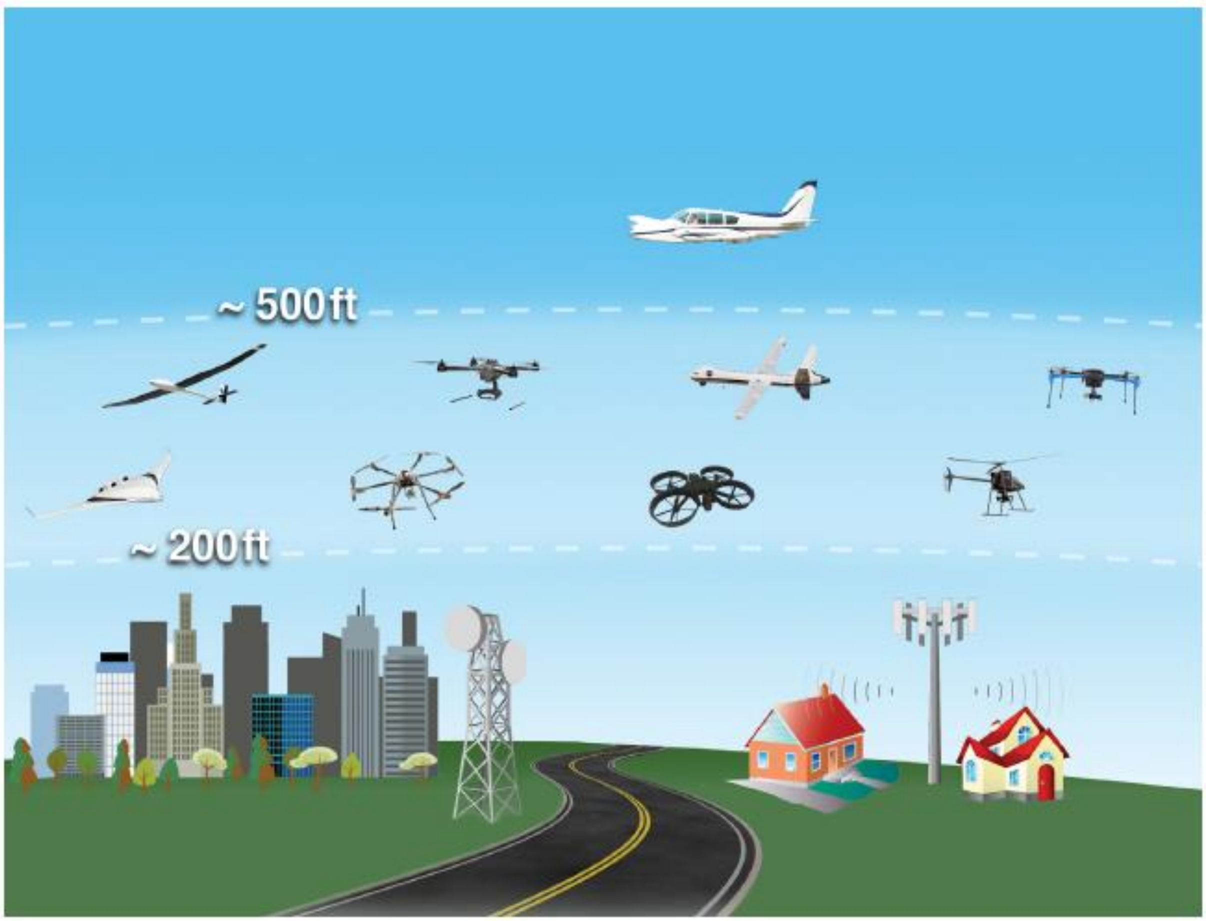

Figure 1.24. UTM

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